

Modelling Low-frequency Vibrations of Light Weight Timber Floors

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Outline

- 1 Introduction
 - Acknowledgement
 - Motivation
- 2 Modelling Procedure
 - Light-weight floor/ceiling system
 - Modelling technique
 - Proposed designs
- 3 Further development of the model
 - Irregularities in the components
 - Including irregularities in the model
- 4 Summary
 - LTFS performance





Acknowledgement

- FWPRDC (Forest and wood product research and development corporation) in Australia.
- Timber product manufactures in New Zealand, LVL, GIB boards, plywood, etc.
- Researchers in Auckland University and the Acoustics Research Centre (engineering, mathematics, acoustics).
- Grant Emms (Scion Research) and Colin Fox (Auckland Univ.).



Motivation for LTFS

Objectives

- Improving low-frequency sound insulation performance.
- Using timber based components.
- As good as concrete slab systems.



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- Improving low-frequency sound insulation performance.
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- As good as concrete slab systems.

Methodology

- New modelling procedure in low freq. range is required.
- Experimental data is required to validate the new model.
- The new model is used to test numerous designs.

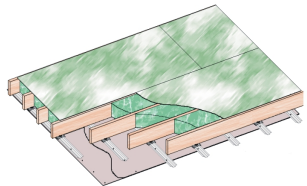




Modelling procedure

Reality

Basic constraint, e.g., material parameters, stiffness, density, preferred construction methods, etc.



Simplest design to be tested:

- Upper plate: plywood, particle board
- Joists: solid timber, LVL, I-beams
- Ceiling panels: plasterboard



Modelling procedure

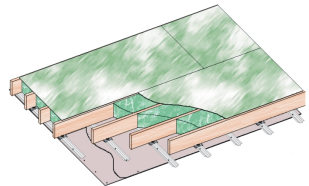
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Mathematics

Mathematical representation (using DEs) of the individual components. DEs are then assembled.



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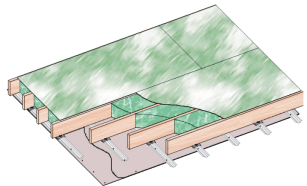
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Experiments

26 designs have been tested. Measurements are detailed enough to validate the model



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Modelling technique

Variational form of the whole structure is derived and minimized using the Fourier basis.

Plate and joist variational forms

$$\frac{1}{2} \int_0^A \int_0^B \left\{ D \left[(\nabla^2 w)^2 + 2(1 - \nu) (w_{xx} w_{yy} - w_{xy}^2) \right] - m\omega^2 w^2 - fw \right\} dx dy$$

$$\frac{1}{2} \sum_{\text{joists}} \int_0^A \left\{ EI w_{xx}^2 - m_j \omega^2 w^2 - f_i w \right\} dx$$

Helmholtz equation for acoustic pressure in cavity

$$\nabla_{x,y,z}^2 p(x, y, z) + \frac{\omega^2}{c^2} p(x, y, z) = 0$$

$$w_i(x, y) = \sum_{m,n=1}^N c_{mn}^i \phi_m(x) \psi_n(y), \quad w_1(x, y) = \sum_{m=1}^N c_{m1}^1 \phi_m(x)$$

For a simply supported structure,

$$\phi_m(x) \propto \sin k_m x, \quad \psi_n(y) \propto \sin \kappa_n y$$

and $k_m = \pi m/A$, $\kappa_n = \pi n/B$ for $m, n = 1, 2, \dots, N$.

Advantages & Disadvantages

- Straightforward implementation to computer codes.
- Computationally efficient, little computational error, a component is represented as a continuous object.
- Simple boundary conditions and geometry



Experiments

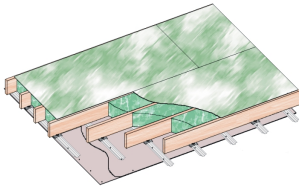


- An electrodynamic shaker applies vertical force.
- A scanning laser vibrometer measures the velocity of the upper plate and ceiling.



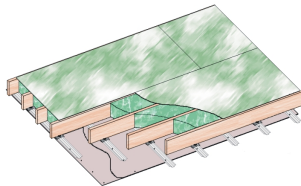
Modelling and experiments

Computation of deflection of upper plate and ceiling.
Determination of uncertain parameters, e.g., damping, dynamic resilience of battens and clips.

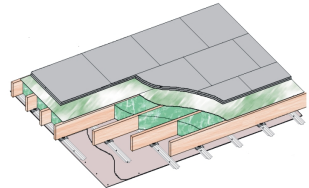


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Adding one or two components, e.g., extra layer on upper plate. Compare the results without adding anything else to the model.

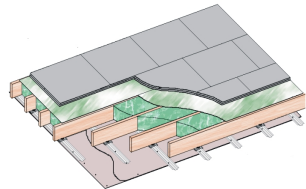
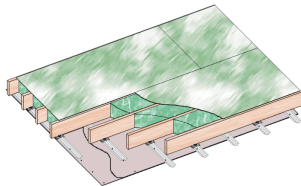


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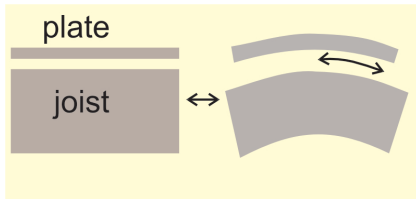
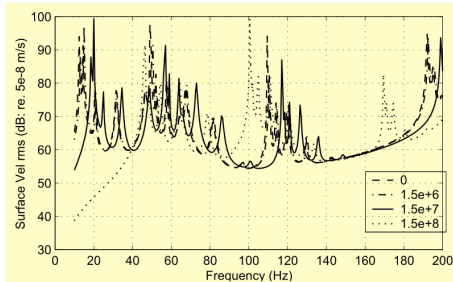


Slippage resistance

Slippage resistance between the upper plate and the ceiling makes a big difference.



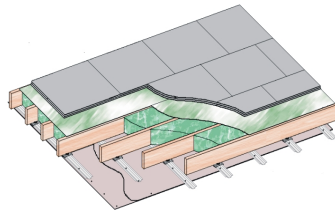
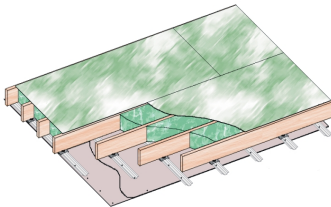
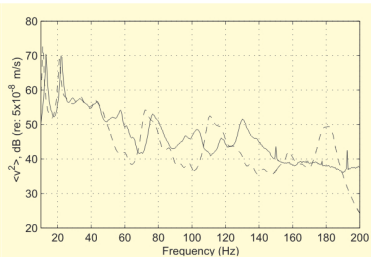
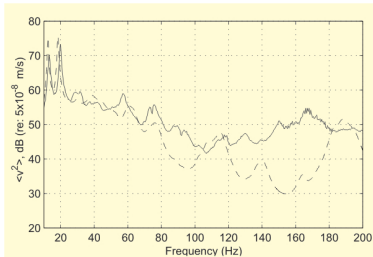
Resonance frequencies



Slip resistance

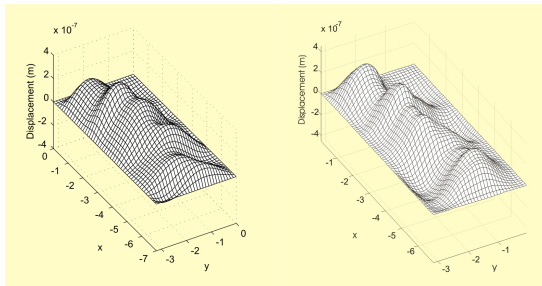
Resistance between the upper plate and the joists moves the resonance frequencies

Computation results



Mode shapes

The computation results are verified by comparing the shape of the modes that are found by inspection of the root average velocity plots.



Modes at 33Hz and 33.5Hz

Left: The ceiling displacement from the model at 33.5Hz. Phase angle 90° from the excitation force. Right: The same mode taken from the experiment measurements at 33Hz.

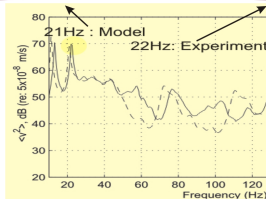


Theoretical
model at 21Hz

Experiment
data at 22Hz

Theoretical
model at 33.5Hz

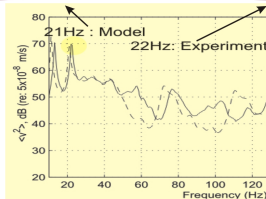
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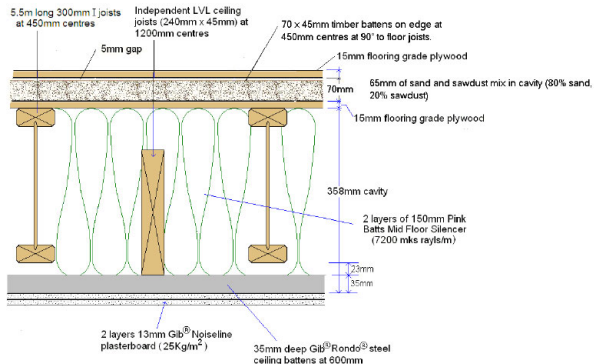
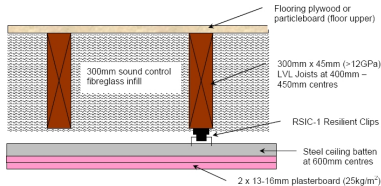
Experiment
data at 33Hz

Other parameters tested

- Damping in plates and cavity
- Batten stiffness
- Resilient clip (rubber) stiffness



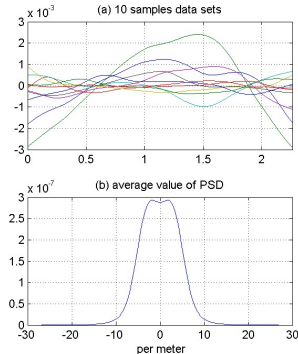
Proposed designs



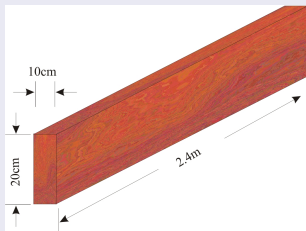
Irregularities

Slippage resistance, twisting joists, Young's modulus of the joists.

An example of twisting timber beams



Measurements of dried timber



Modelling irregularities

$\theta(x, j)$: joist shape.

$\sigma_0 + \sigma(x, j)$: contact rigidity,

$\epsilon_0 + \epsilon(x, j)$: Young's modulus.

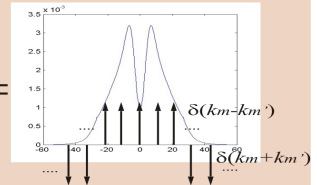
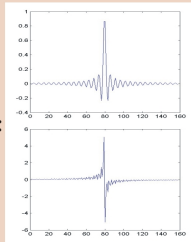
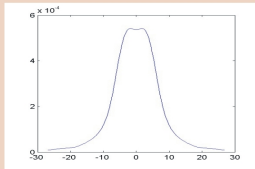
For example, varying joist shape is coupled to the plate

$$\mathbf{c}_1 = [\mathcal{L} + \mathcal{L}_\theta] \mathbf{c}_0.$$

\mathcal{L} : straight beams, \mathcal{L}_θ : deviation from the straight line.

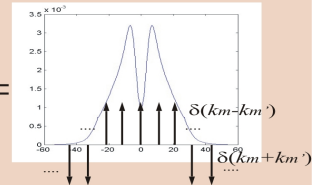
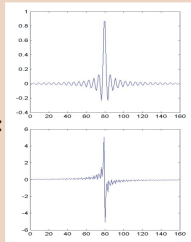
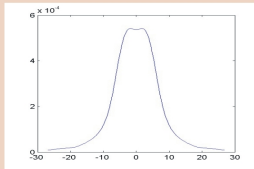
$$[\mathcal{L}_\theta] \sim \left[\hat{\theta} * \hat{H} * \{ \delta(k_m - k_{m'}) - \delta(k_m + k_{m'}) \} \right]$$





$$\hat{\theta} * \hat{H} * \{ \delta(k_m - k_{m'}) - \delta(k_m + k_{m'}) \}$$





$$\hat{\theta} * \hat{H} * \{\delta(k_m - k_{m'}) - \delta(k_m + k_{m'})\}$$

Further research

- ① Run stochastic simulations based on the PSD of either measured or simulated irregularities.
- ② Determine which (or if) irregularities have the dominant effects on the vibration in the frq. range $> 80\text{Hz}$.



Summary

- 1 Detailed studies of individual components are necessary
- 2 Prediction in the low-frequency range is possible
- 3 New designs of LTFS are tested using the model
- 4 More details available at: www.fwprdc.org.au
- 5 Planning to run simulations based on the PSD of the irregularities



Subjective testing



G. Dodd has been conducting subjective listening test to devise a rating criteria for the LTFS. A test subject listens to recordings from two different mockup floors and compare them according to rating system given by Dodd.

